EM SaiTeD

Bibliography and Specification of Target Emissions

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EM SaiTeD Consortium:

INECO Ingenieria y Economia del Transporte ESP
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas ESP
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Summary

The document contains the Bibliography of the EMSaiTed project.

It is not a self contained document but it explains the scientific basis of the project and the emissions which will be targeted out of an in depth literature research. The final document of the project will integrate the bibliography.

The emissions which will be studied in particular will be CO$_2$, H$_2$O and NOX: they are currently regarded as the most important polutive gas coming from aviation and have the greatest (IPCC 2007) recognised impact on climate change. There detection by satellite based tools (in appendix table with tools and gas detection species capability) is the focus of the viability study, although a preliminary analysis of the Bibliography already gives us some results on there estimation or at least detection by the current satellite sensors. In particular detection of CO$_2$ and H$_2$O, as air traffic tracers, may have some limitations already identified at the beginning of the project (see section. 4).

The key part of this project is the study of a simulated scenario (as calibration) followed by a real scenario (routes and traffic) and its analysis aimed at understanding the capability of satellite based sensors to estimate or quantify important polutive species typical of aviation. It is therefore very important that the bibliography and the preliminary research make sure the scenario chosen is fail prove and the framework or its boundaries are sustained by concrete hypothesis (i.e. dispersion of an aircraft plume is less than the distance among routes, making these routes independent).

Following the same line of thought this report gathers the main findings on the chemical composition and behaviour of aviation’s emissions on the UTLS. These will be used for the route scenario definition and the viability assessment of the remote sensing tools, but most of all it will define the atmospheric background we find when there is or there is no aviation present.

The conclusions found in this document will be used throughout the project and will support and direct the projects future development stages.
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1 Introduction

1.1 Introduction

The following document as a Bibliography, collects in a minded structure, all the information on which to base the viability study of the EMSAITED project. For this reason this document cannot be seen as a final deliverable, rather as the building block of the final deliverable of the project.

The Bibliography has been conducted in two phases, both phases are included in this document.

PHASE 1, the Bibliographic Research is a collection of necessary information in particular the literature collected covered three clearly different aspects each pursuing an independent, but at the same time complementary objective.

The information searched included:

1. Emission model/Databases/ General aspects on the environmental impact of aviation: in particular knowledge of the chemical characteristics of aircraft emissions. Their evolution in the past years and possibly the forecast in the mid-term.

2. Satellite data and measurements: Analysis of the results (data) delivered from space (remote sensing) based instruments capable of measuring atmospheric components, with special emphasis on the vertical distribution of the distinct pollution traces.

3. Aircraft in-situ measurements: Knowledge on the concentration of certain plume compounds measured next to the Tropopause which may be directly linked to the emissions produced by air traffic, or that can be related to its impact on the environment (i.e. Ozone production, Methane decomposition, etc.). Collection of the conclusions of all the different projects developed in the past ten years concerned with the evolution of the chemical composition of the upper troposphere/lower Stratosphere and its relation with aviations emissions.

PHASE 2, Lit. Review and Bibliography Analysis concentrated on the analysis of all the information collected above in order to support the viability study by defining the target gases and pollutants; the starting point for the viability study built on previous work and creating the supportive structure for the further phases of the project.

1.2 Purpose

The purpose of a Bibliography is to understand the environment surrounding the project’s aims and scenarios and most of all:

- to make sure the study, in our case the viability study, has a robust foundation and does add more knowledge to work already done in the past;
- answers questions on the capability of current remote sensing monitoring tools for en-route air traffic emissions detection and observation;
- opens new possibilities to the Assessment and Monitoring of the Environmental Impact of Air transport;
- to make sure the scenarios which will be evaluated (Exercise 1 and Exercise 2) are robust and all the background concerning there study is known;
- target the currently most important gas species from the aviation emissions, making sure they are reasonably detectable by satellite base tools and current interest in their Environmental impact.;
- And lastly enables the reviewer and the project’s team to check during the project (as a checklist) the consistency of the developments and the supportive scientific basis for the study;

1.3 Methodology applied to the project

The planned methodology for the development of the viability study considers as fundamental to begin from the scientific knowledge accumulated in the following areas:

- Emissions produced by aircraft
- The chemical and physical behaviour of these emissions in the UTLS (Upper Troposphere Lower Stratosphere)
- The performances of the current remote sensing tools and the ones planned in future missions.

This knowledge will enable us to carry out a simulation exercise (EX1) in which a clear idea will be obtained on the concentrations which are usually reached along the air routes with heavy traffic. This data will be later used to define certain basic characteristics which a sensor should include in order to be able to detect those emissions.

The analysis will also embrace those space based databases which may bring useful information in terms of air traffic emissions identification for a certain route selected for its interest and suitability.

As a preliminary step, it has been considered as essential to study the documentation of the past 15 years related to those international projects which had as an aim the in depth study of the experimental characterisation of the upper troposphere by in-situ measurements conducted normally on board aircrafts. By this, the state of the art with reference to the documented behaviour of aviation’s emissions in the higher layers of the troposphere can be determined, as well as knowledge on the background concentrations together with its variability in space and time.

In parallel to this it is as relevant to study that bibliography which is specifically dedicated to the theoretical and experimental study of the emissions dispersion generated by aviation along the air-routes. This way the spatial and time based evolution of the individual plumes can be estimated inside a virtual air-route which will enable us to carry out a simulation exercise on the typical behaviour of a region of the atmosphere, frequently used by air traffic, in terms of its chemical composition.
For this exercise it is also essential to know the emissions generated by the current aircraft in the most exhaustive and realistic manner, reason why it will be necessary to use the results from the most updated and solid aircraft emissions model we have available (in our case the AEM III courtesy of EUROCONTROL, will be used).

Based on all this data the project will be able to highlight the minimum technical requirements that a space sensor would have to fulfil in order to be able to detect/quantify the gas presence related to the airplanes’ emissions in the layer between 8-12Km of height.

An analysis will also be conducted, following the same terms as above, of a real case (EX2) corresponding to an air-route or air-corridor for which sufficient information is known on the traffic that it supports and presenting an adequate profile in terms of stability and intensity of the demand.

With respect to the diagnosis on the potential for the present space sensors to identify tracer compounds related to air traffic emissions, the idea is the following one:

- those satellites which are able to measure in a reliable way the atmospheric composition will be identified;
- between all of them, those that can contribute information on some tracer compound from aircraft emissions, for example NO2, will be selected and finally the performances of its different measuring modes will be studied.

In those cases for which a real possibility exists of obtaining positive results, the relative databases will be analyzed in search for those cells which correspond to the air-route selected for the exercise previously described.

Summarizing the bibliography is key for the definition of the scenarios boundaries and the development of the satellites viability diagnosis.

### 1.4 Bibliographic development.

The Bibliographic work was divided in two phases Collection and Review.

The aim of the first phase being the identification and collection of all the previous work concerned with Aircraft-Satellites-Emissions was developed in four different directions in order to identify precisely what is the most important information and what was going to be needed by the project:

- Identification of international projects dedicated to the experimental gathering in-situ (on site monitoring flights) of the chemo-physical characteristics of the upper atmosphere (Troposphere, upper troposphere, tropopause, stratosphere) and to those studies concerned with air traffic emissions’ possible influence. Publications, papers, generated databases.
- Identification of those satellite missions having the required range and spectral resolution for allowing the detection of gases linked to aircraft emissions. Publications, papers, generated databases.
- Collection of other references or material which may be related to the subject of aircraft emissions, its detection and its effects on the atmosphere.
During the second phase all the information previously collected was analysed. The reader will have to bear in mind that this phase does not finish with the Bibliography but continues throughout the other phases of the project until the conclusions are made.

The objectives of this phase were and are:

- To know the existence of possible experimental initiatives aimed at the teledetection (be it based on remote sensing or ground infrastructures) of trace gases in the higher troposphere or the stratosphere that may be attributable to the air traffic emissions.
- To evaluate the state of the art in the subject of evaluating the direct or indirect impact of air traffic emissions on the atmosphere.
- To compile experimental evidence, obtained with whatever experimental media, on the anomalous presence in the higher layers of certain gases linked to air traffic emissions. Documentation on the evolution of these gas concentrations and the existence of preferred accumulation areas (spots) i.e. air traffic routes.
- Identification of ideal scenarios (areas/air traffic routes, periods and the most convenient meteorological conditions) for research, in the available teledetection databases, of possible evidence relatively to the presence of gaseous traces or alterations in the atmosphere’s composition in certain zones, attributable to air traffic emissions.
- Selection of the most promising teledetection database for its later analysis.

Clearly different objectives but complementary for the viability study which will follow.

1.5 Background

Much pressure is now being put on ATM system by the public on the basis of its increasing environmental influence: Noise, Local Emissions and Climate Change are the main environmental problems faced by the air transport industry. Although much has been done in the last three decades concerned with both noise and emissions (technological improvements of both aircraft and power units) more is required, even more so when traffic demand forecasts a net 4% increase in the following years.

Aviation is growing faster than any other transport mode and CO$_2$ emissions grew by 62 % in the 15 old EU Member States between 1990 and 2003. Therefore, aviation (including international aviation) now accounts for 13.6 % of transport (including international aviation but excluding maritime transport) CO$_2$ emissions$^1$.

Among all the environmental aspects one which is of great importance for its global focus is: Climate Change. The introduction of greenhouse gases like CO$_2$ and Ozone in the atmosphere as well as aerosols and water vapour (potential maker of Cirrus Clouds).

Although the estimated share of aviation’s CO$_2$ stands at about 12% (according to the Intergovernmental Panel on Climate Change’s (IPCC)$^2$, against a 75% coming from road transport, the feeling is that the potential emissions at heights flown by modern air transport have a higher and more direct influence on the atmosphere in particular the operational en-route segment Upper Troposphere Lower Stratosphere region (UTLS).

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$^2$ “Special Report on Aviation and the Global Atmosphere (published in 1999)”
The proposed study will benefit from the on-going research carried out by the international scientific plateau but by adding the aeronautical aspect and the consideration for an environmentally sustainable Air transport.

Since the beginning of the 90’s many scientific international projects have focused specifically on trying to document the effects of air traffic emissions on the composition of the higher Troposphere Lower Stratosphere on a global level. The implementation has although been always based on different techniques. Most of them theoretical, based on aircraft emissions modelling and its dispersion through simulation and chemical interaction with the atmosphere, in parallel purely experimental projects looked into documenting the reality of these processes.

Seldom has satellite data been used for this purpose, and even less when concerning Air traffic.

The ‘Global Monitoring for Environment and Security’ (GMES) represents a concerted effort to bring data and information providers together with users, so they can better understand each other and make environmental and security-related information available to the people who need it through enhanced or new services. It is now at the second stage “implementation”.

1.6 Document Structure

The document has been divided into three main parts or sections:

- Section 1: A broad introduction with the background to the study, aviation's impacts on climate and specification of aircraft target emissions as estimated so by their implication and importance in influencing climate change.

- Section 2: The analysis and review of the most recent and important literature relevant to this study and the conclusions made: this will serve as foundation for building the project and follows the structure of objectives listed in 1.1.

1.7 Partnership

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3 Actual documentation on the use of satellites for the Detection of air traffic originated emissions in the UTLS region is very scant. Although projects exist (like TROPOSAT, ACCENT-TROPOSAT2) where the study of NOx emissions (originated by various sources) is tackled, starting from satellite based data.
1.8 Overall aim of the EMSaiTeD project and work proposed

The objective of the proposed study is to evaluate the possibility of estimating air traffic emissions during the en-route segment of flight with remote sensing and statistical tools.

The study will analyse the viability of using remote sensing technology in the air traffic system as a way to weigh its contribution and to highlight the possible pattern of emissions coming from one industry (air transport) in the UTLS region of the atmosphere.

1.9 Glossary

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<td>UTLS</td>
<td>Upper Troposphere/Lower Stratosphere</td>
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<td>Cirrus</td>
<td>High-level clouds (16,000 feet or more), composed of ice crystals appearing in the form of white, delicate filaments or white or mostly white patches or narrow bands.</td>
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2 Target Aircraft Emissions

2.1 Introduction

Aircraft emit gases and particles directly into the upper troposphere and lower stratosphere where they have an impact on atmospheric composition. These gases and particles alter the concentration of atmospheric greenhouse gases, including carbon dioxide (CO$_2$), ozone (O$_3$), and methane (CH$_4$); trigger formation of condensation trails (contrails$^4$); and may increase cirrus cloudiness—all of which contribute to climate change [Aviation and the Global Atmosphere, Special Report (IPCC 2001)].

The aim of this section is to list those emissions coming from aviation which are currently realised to be influencing climate change together with some background.

The list of aircraft emissions targeted as influencing climate change will be thus found hereafter. In section (3.2) the list of emissions (gases) currently detectable by remote sensing space based tools is available:

Crossing of the two lists to see current remote sensing detection capabilities will be part of the viability study.

2.2 Aircraft Emissions & the Atmosphere

Most present-day jet aircraft cruise in an altitude range (9-13 km) that contains portions of the UT and LS. Because these two atmospheric regions are characterized by different dynamics and photochemistry, the placement of aircraft exhaust into these regions must be considered when evaluating the impact of exhaust species.

When we talk about aviation emissions we are talking about emissions from engines (mainly jet engines) and APUs (Alternative Power Units). The second affecting mostly local air quality$^5$.

The chemical products of aircraft jet fuel combustion (Fig. 2) are emitted at the engine nozzle exit plane as part of a high-velocity plume. This gaseous and particulate stream is subject to chemical and dynamical processes that influence downstream composition.

Eventually, plume constituents irreversibly mix with, and are diluted by, ambient air. Subsequently, some of the emitted species act in concert with other natural and anthropogenic chemicals to change the gas concentrations in the Earth's atmosphere (2.3). The ultimate fates of these aircraft-derived species are determined by larger-scale chemical and transport processes.

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$^4$ Cirrus formation and Contrails will not be studied in depth if not for those aspects which may be interesting for emissions detection (aerosols dispersion, optical thickness, diffusivity, etc..).

$^5$ Air quality will not be interested by the project since only the en-route segment of flight is considered (8-13km).
Fig. 1. Aviation and the Global Atmosphere, Special Report (IPCC 2001)

The principal emissions of aircraft include the greenhouse gases carbon dioxide and water vapour (H₂O). Other major emissions are nitric oxide (NO) and nitrogen dioxide (NO₂) (which together are termed NOx), sulfur oxides (SOx), CO and soot.

**FUEL**

Carburant : C₁₀H₂₀ S

**Exhaust Gases**

- Foul air : 75,2% N₂, 16,3% O₂
- Combustion Products : 6,1% CO₂, 2,35% H₂O
- 0,02% SOx
- Pollutants: < 0,05%
  - CO, UHC, NO, NO₂
  - Soot, Black carbon (C)

Fig. 2. Engine exhaust products (MOZAIC III, Airbus)

The full climate impact of aviation goes beyond the effects of CO₂ emissions, though. Apart from emitting CO₂, the aircraft contribute to climate change through the emission of NOx which are particularly effective in forming the greenhouse ozone when emitted at cruise altitudes.
On the other hand aircraft's impact on methane (another greenhouse gas) as well, although it is very small and negative: aircraft NOx enhances OH, OH reduces CH₄, so that CH₄ is reduced by aircraft.

This effect on the other hand is very small compared to the large increase in CH₄ due to Industrialization (personal letter with Michael Gauss, TRADEOF) and although globally the numbers between positive and negative impact (ozone production vs. methane decomposition) may balance, regionally this is not the case due to there different distribution.

Water vapour is extremely important for the formation of contrails (Condensation trails). Contrails are aircraft induced cirrus clouds, which may persist and grow to large cirrus cover in ice-supersaturated air, and may cause a warming of the atmosphere.

Work is still ongoing on the evaluation of its impact on climate change, currently its contribution to the greenhouse effect is understood to be positive, although its magnitude is still uncertain and cause for debate.

The EMSAITED project will focus essentially on three types of emissions: H₂O, NOx and CO₂, as they are currently the most important on the aviations environmental scenario.

### 2.3 Emissions inventories and models

The total amount of aviation fuel burned, as well as the total emissions of carbon dioxide, NOx, and water vapour by aircraft, are well known and are well referenced depending on engine model and mode of operation through databases or calculated inventories (Fig. 3). Other species contained in the aircraft plumes as soot and PMI's are also under screening for Health reasons and local air quality, pushing for these species to be added to current inventories as well.

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6 Currently the CONTRAIL project is studying this phenomena with the aid of remote sensing tools among others the Meteosat satellite.

7 FORMATION, PROPERTIES AND CLIMATIC EFFECTS OF CONTRAILS, COMPTES RENDUS PHYSIQUE (2005), Ulrich Schumann

8 ICAO Engine Emissions Databank

9 EMEP/CORINAIR Emission Inventory Guidebook - 2006
On the other hand work is still ongoing on different fronts (i.e.: emissions model development: SAGE\textsuperscript{10} or AEMIII\textsuperscript{11}) to make these estimations less conservative, more accurate and reflect more current day operations.

For the scope of the EMSaiTed project the AEMIII software will be used for air traffic en-route emissions’ estimation and will be applied to a real air-route in order to estimate the magnitude of the emissions and the different species of gas concentrations.

The future use of these models and inventories, at least in Europe will be decisive, if and when the Emissions Trading System will be extended to the air transport industry as well\textsuperscript{12}.

\textsuperscript{10} System for Assessing Aviation’s Global Emissions (SAGE)-FAA
\textsuperscript{11} Advanced Emission Model (AEM3). The Advanced Emission Model (AEM3) is a stand-alone system used to estimate aviation emissions (CO2, H2O, SOx, NOx, HC, CO, Benzene, VOC, TOG) and fuel burn. It is able to analyse flight profile data, on a flight-by-flight base, for air traffic scenarios of almost any scope (from local studies around airports to global emissions from air traffic).
\textsuperscript{12} P6_TA-PROV(2006)0296 Reducing the climate change impact of aviation. On 20th December 2006, the Commission adopted a proposal for legislation to include aviation in the EU Emissions Trading Scheme (ETS). The proposal provides for aviation to be brought into the EU ETS.
3 Conclusions of the Bibliographic Research

The bibliography used in the development of the first stage of the EMSaiTed Project has been clustered in three groups corresponding to three basic topics considered crucial to present the state-of-the-art in the object proposed by the project.

3.1 Chemical composition of the air in flight corridors or in atmospheric layers influenced by air traffic emissions. Main results from experimental projects.

CONCLUSIONS:

- The trajectories flown by aircraft during the flight segments on international routes spend nearly the same amount of time in the Upper Troposphere as in the Lower Stratosphere. The exact time spent depends on the definition of the reference potential verticity, which is used to situate or delimit the tropopause but, in general terms, the time shares are very similar. For example, along the North Atlantic flight corridor, it is well documented that aircraft along the route are practically half the time flying above the tropopause while the other half below it. This conclusion is crucial, because the atmospheric dispersions of emissions for both cases can be very different together with the related atmospheric effects. (Brunner D, et al, *J. Geophys. Res.*, 106 (D21): 27673-27699, 2001)

- All the experimental results highlight and demonstrate that the concentration of gaseous traces measured at heights and in areas which correspond to air traffic routes (corridors), or relatively close to them present a strong variability in space and time, thus, great heterogeneity. This is due to various reasons among which stand out the different dispersion conditions specific to the different studied areas: the seasonal variability in height of the tropopause with latitude and the atmospheric transport towards the upper troposphere of those compounds related to emissions produced on the earth’s surface. (Emmons, L.K., et al., *J. Geophys. Res.* 105, D16, 20497–20538, 2000.)

- The presence of NOx in the UTLS region is influenced by the air traffic. The background NOx concentration in the layer between 8-12km presents a clear latitudinal gradient for the Northern Hemisphere with minimum values (20-40pptv) close to the Equator and maximums (200-3000 pptv) in latitudes between 50-60º N. Inside the general strong variability the detected concentrations are usually highest for those zones influenced by air traffic corridors (routes), as demonstrated by the data coming from vertical profiles obtained through different experiments realized with in-situ measurements. These Nox vertical distribution results from areas with air traffic, show significant concentration increases at altitudes used by aircraft, as well as a non homogenous distribution of emissions' tracers existing inside the 8-12km layer and a behavior dependant on height. (Ziereis, H. et al., *J. Geophys. Res.* Vol. 105 , No. D3 , p. 3653 (1999JD900870), 2000).
The NOx concentration in the UTLS presents a seasonal behavior when the annual evolution of NOx is analysed for constant altitudes. It is well documented that changes observed in the Northern Hemisphere correlate positively with thunderstorm activity in such a way that in summer time their increase explains the increase in NOx close to the Tropopause during the warm season and is also responsible in great measure for the observed variability in the concentrations measured during the summer time. (Ziereis, H. et al, J.Geophys. Res., 104, 16021-16032, 1999)

The evolution of the emissions produced by aviation in terms of yield of NO2 formation is a function of the height the aircraft is flying. This is due to the fact that the oxidation frequency for NO in the UTLS is clearly less than the one found for the lower troposphere to the point that the maximum ratio NO2/NOx reaches in between 8-12km is lower than 40%. The reason for this stands in the oxidation mechanisms of NO which are severally controlled by temperature. Photoxoidation of NO2 can also affect this but is less influential. (Ziereis, H. et al, J.Geophys. Res., 104, 16021-16032, 1999)

The maximum concentrations of NOx normally observed in recent plumes (lifetime below 3h) produced by aircraft are below 2ppb, which represents and increase over the background values of a factor of 10-100. (Schlager H, et al, J. Geophys. Res. 102 (D9): 10739-10750, 1997).

References


3.2 Space remote sensing: satellites, sensors, products and main results regarding the application of RS tools to the investigation of atmospheric chemical composition vs. pollutant sources.

CONCLUSIONS:

- List of sensors/satellites and products (see Annex I 0)

- Selection of sensors with proved NO\textsubscript{2} detection potential between 8-12 Km and presentation of their main characteristics. (Annex II)

- Important concentrations of CO have been detected at different altitudes over various regions of the Southern Hemisphere which can be attributed without doubt to the burning of biomass in South America, Africa and Australia. Other combustion tracers related to biomass and industrial pollution (O\textsubscript{3}, C\textsubscript{2}H\textsubscript{6}, C\textsubscript{2}H\textsubscript{2}, HNO\textsubscript{3} y PAN) have also been detected (MIPAS) in the upper troposphere forming great plumes. This has demonstrated, among other things, that the nitrogenated species can be transported thousand of miles from emissions’ zone and that they can reach altitudes close to the Tropopause. (C. Clerbaux et al, ACCENT-TROPOSAT-2 Report 1 2007, TG1 66-73; G.P. Stiller et al, ACCENT-TROPOSAT-2 Report 1 2007, TG1 183-188; von Clarmann et al, Atmospheric Science Conference, ESRIN, Frascati, 8-12 May 2006; Glatthor, N. et al, Atmospheric Science Conference, ESRIN, Frascati, 2006).

- Unique concentrations of O\textsubscript{3} have been detected at different altitudes (TE5) over Intertropical regions and these increases over the regional’s ozone background, have been related with the burning of biomass in Africa. (Jourdain L. et al, Geophys. Res. Lett. 34, L04810, 2007).

- Noticeable increases in Methanol (CH\textsubscript{3}OH) have for the first time (FTS) been detected at high altitudes over regions situated south of the equator. These abnormal high concentrations of methanol have been strongly correlated to the presence of other biomass combustion tracers. (Dufour G. et al, Atmos. Chem. Phys., 6, 3463–3470, 2006).

- Monitoring of the frequency of persistent contrail’s formation and cirrus over various regions of the earth has been achieved, by crossing satellite information (AVHRR y Meteosat) with air traffic routes. A positive connection has been clearly demonstrated between cirrus formation and airtraffic. The optical thickness defined for the detected and the analysed contrails showed values between 0.1 y 0.2. (Status Report 1997-2003 Part 1 DLR ; Meyer R. et al. J. Geophys. Res., 107, D10 (10.1029/2001JD000426), ACL 17-1-ACL17-15, 2002).

- By crossing tropospheric NO\textsubscript{2} (GOME) column results with chemical transport models, the contribution of thunderstorms to NO\textsubscript{2} columns has been estimated for the observed columns, although it is recognised that quantification of NO\textsubscript{2}in these cases is very difficult, among other things due to the presence of clouds associated with the above atmospheric phenomenas. (Choi Y. et al, Geophys. Res. Lett. 32, L02805, 2005).
There have been attempts in estimating the contribution of storms to global atmospheric NOx production, starting from data coming from space sensors capable of detecting atmospheric electrical discharges. Specifically, images produced by the OTD/Microlab-1 over the distribution of discharges at a worldwide level during a whole year, were the basis for the calculations. The difficulty in knowing the exact height at which these discharges (lightning) occur (Intra-cloud or cloud-to-ground lightning) is one of the main limiting aspects when trying to sufficiently determine the reliability of the contribution to NOx concentration in each layer of the atmosphere. It has also been considered as very difficult to clearly identify the long-distance advection of NOx produced by a specific storm cell. (Sauvage B. et al, *Atmos. Chem. Phys.*, 7, 815–838, 2007; Christian,HJ et al, *J. Geophys. Res.*, 108 4005, doi: 10.1029/2002JD002347, 2003).

The tropospheric column measurements for NO$_2$ (SCIAMACHY) have shown that certain relative enhancements in NO$_2$ detected in specific regions of the southern Hemisphere do correspond to maritime traffic which takes place along four very busy international routes. These routes are situated in: the Red Sea, India-Indonesia and the NW Indian (Richter A. et al, *J. Geophys. Res.*, 31 L23110, 2004).

References


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18. Annemieke Gloudemans, Hans Schrijver, Wouter Hartmann and Ilse Aben, Retrieval of SCIAMACHY CO, CH4 and CO2 TG1 100-103.


3.3 Atmospheric dispersion of aircraft plumes

CONCLUSIONS:

- The dispersion of Plumes produced by aircraft flying at cruise altitude disperse in two phases. The first phase is governed by the turbulence generated in the air by the flying aircraft (dispersion regime) while the second is governed purely by atmospheric processes: circulation and transport (circulation regime). The resulting plume will disperse in tens of meters or kilometres, depending on the atmospheric conditions, taking up to a whole day to mix homogeneously inside the air route. (Schumann U. and Konopka P., DLR-Mitt, 94-06, 1994)

- The typical vertical diffusivity for recent plumes (below 100 min from emission) produced by commercial aircraft in cruise altitude are generally below 0.6 m$^2$s$^{-1}$. This means that, for stratified atmosphere and light wind shear conditions. This means that, the vertical extensions usually reached by individual plumes during its diffusion at these altitudes are under 200m. (Schumann U. et al, J. Geophys. Res.100 (D7): 14147-14162, 1995).

- The typical horizontal diffusivity for recent plumes (less than 100 min from emission) produced by commercial aircraft in cruise altitude is generally in the range 5-20 m$^2$s$^{-1}$. This implies that, for these times, the plumes' diffusion can reach a typical lateral extension between 500-2000m (width at mid-height) in moderate Windshear conditions. (Schumann U. et al, J. Geophys. Res.100 (D7): 14147-14162, 1995).

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4 Specific Aircraft Emissions targeted by the project and scope limitations (CO₂ and H₂O)

In the frame of the EMSAITED project the decision was made to target three specific and currently most discussed and relevant gases: CO₂, NOx and H₂O. Due to their importance both for the current aviation environmental discussion plus for the scenario which will be studied in the project, a preliminary study was conducted on the traceability of these gases from space.

In fact as previously described (section 2.2) the most abundant emissions produced by an aircraft correspond to CO₂ and H₂O. On the other hand, the high concentrations of these species in the atmosphere greatly hinder their measurability.

For the specific case of detecting CO₂ from space, currently three possibilities exist:

a) Vertical sounding of the atmosphere based on radiance measurements for different regions of the infrared (sensors TOVS, AIRS and IASI).

b) The DOAS (Differential Optical Absorptions Spectroscopy) technique based on differential absorption in the near infrared (SCIAMACHY, and the future OCO and GOSAT\(^1\)).

c) The DIAL (Differential Absorption LIDAR), as a future option.

Starting from the use of the two passive techniques a) and b) we may obtain two types of results: concentration values of CO₂, representatives of the explored regions or the matching CO₂ dry air column averaged mixing ratio (CO₂). For both these cases the objective fundamentally consists in detecting the changes that occur in the concentration of CO₂ at a global level in the mid and long-term. Consequently, there is no pretension to obtain a great time and space resolution rather detect the variations of a certain magnitude in the CO₂ levels which relate to changes in CO₂ concentrations and not due to interferences produced by other atmospheric constituents.

As such, the presence of aerosols and the variations in humidity and pressure along the used optical paths are the greatest identified source of interference, which in practice often hinders reception of useful data for the scope earlier described (and part of the EmsAITed objective).

Many of these problems come from the fact that these sensors were not designed specifically for the measurement of CO₂ and the data for these gases are obtained from a complicated and arduous processing of the available bands, thus presenting the results with numerous difficulties.

The future use of specialised sensors for the measurement of CO₂ (OCO and GOSAT for example) could mitigate this situation, although the aim still remains to obtain representative average values of column CO₂ from each studied region.

The use of many more wave-bands, plus the inclusion of new measuring modes and the previously built experience obtained with SCIAMACHY will be useful in extending CO₂ measurements to situations and areas for which the reception of data is currently difficult.

Still, from the results which will be obtained during the simulation exercise on real traffic data along an air route (EX2), the increases in CO₂ concentrations will be estimated in a realistic manner, as

\(^{13}\) Greenhouse gases Observing SATellite (JAXA)
produced by aviation inside the atmospheric layers interested by air traffic. This data will enable us to
determine if the future sensors will be able to detect these variations over the existing CO\textsubscript{2}
background.

Concerning the H\textsubscript{2}O emissions, its great variability in the atmosphere greatly hinders its use as an air
traffic emissions tracer, although the viability of using the humidity profiles obtained from space will be
explored in order to deliver useful information.

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**AIRS /CO$_2$**

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**IASI /CO$_2$**


**OCO /CO\textsubscript{2}**


**GOSAT /CO\textsubscript{2}**


**CO\textsubscript{2} in situ**


## ANNEX I: Annex 1 - Main Space Remote Sensors devoted to atmospheric composition research

<table>
<thead>
<tr>
<th>SATELLITE</th>
<th>ORBIT</th>
<th>SENSORS</th>
<th>ATMOSPHERIC CONSTITUENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENVISAT</td>
<td>Near polar sun synchronous at 800 km.</td>
<td>SCIAMACHY</td>
<td>O₃, BrO, OCIO, ClO, SO₂, H₂CO, NO₂, CO, CO₂, CH₄, H₂O, N₂O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MIPAS</td>
<td>O₃, ClO, NO₂, CO, CH₄, H₂O, N₂O, NO, HNO₃, HNO₄, N₂O₅, ClONO₂, CFC’s, HOCl, H₂O₂, C₂H₂, C₂H₆, OCS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GOMOS</td>
<td>O₃, NO₂, NO₅, H₂O, O₂, aerosols.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MERIS</td>
<td>H₂O, aerosols</td>
</tr>
<tr>
<td>ERS-2</td>
<td>Near polar sun synchronous at 800 km.</td>
<td>GOME</td>
<td>O₃, BrO, OCIO, SO₂, H₂CO, NO₂</td>
</tr>
<tr>
<td>ACE</td>
<td>650 km, 74º inclination</td>
<td>FTS</td>
<td>H₂O, O₃, N₂O, CO, CH₄, NO, NO₂, HNO₂, HF, HCl, N₂O₅, ClONO₂, CCl₂F₂, CCl₃F, COF₂, CHF₂Cl, HDO, SF₆, OCS, HCN, CF₄, CH₃Cl, C₂H₂, C₂H₆, N₂, ClO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAESTRO</td>
<td>O₃, NO₂</td>
</tr>
<tr>
<td>AURA</td>
<td>Near polar, sun synchronous orbit at 705 km.</td>
<td>TES</td>
<td>H₂O, O₃, CO, CH₄, NO₂, HNO₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OMI</td>
<td>O₃, OCIO, SO₂, NO₂, BrO, HCOH, aerosols</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MLS</td>
<td>O₃, CO, H₂O, N₂O, HNO₃, HOCl, OH, HCN, HCl, BrO, ClO, SO₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HIRDLS</td>
<td>O₃, H₂O, N₂O, HNO₃, ClONO₂, CH₄, NO₂, N₂O₅, CFC-11, CFC-12, aerosols</td>
</tr>
<tr>
<td>METOP</td>
<td>Near polar, sun synchronous orbit at 817 km.</td>
<td>GOME 2</td>
<td>O₃, OCIO, NO₂, BrO, H₂O, O₂, aerosols</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IASI</td>
<td>O₃, N₂O, CO, CH₄, aerosols.</td>
</tr>
<tr>
<td>ODIN</td>
<td>Near polar, sun synchronous orbit at 600 km.</td>
<td>OSIRIS</td>
<td>O₃, ClO, N₂O, HNO₃, CO, H₂O, NO₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SMR</td>
<td>O₃, N₂O, H₂O</td>
</tr>
<tr>
<td>TERRA</td>
<td>Near polar, sun synchronous orbit at 705 km.</td>
<td>MOPITT</td>
<td>CO, CH₄</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MODIS</td>
<td>H₂O, aerosols</td>
</tr>
<tr>
<td>UARS</td>
<td>585 km, 57º inclination</td>
<td>HALOE</td>
<td>O₃, H₂O, HCl, HF, CH₄, NO₂, NO, aerosols</td>
</tr>
<tr>
<td><strong>AQUA</strong></td>
<td>Near polar, sun synchronous orbit at 705 km.</td>
<td><strong>AIRS</strong></td>
<td>O₃, H₂O, CO, CO₂, CH₄, SO₂, aerosols</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------------------------------</td>
<td>----------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>MODIS</strong></td>
<td>H₂O, aerosols</td>
</tr>
<tr>
<td><strong>METEOR-3M</strong></td>
<td>Near polar, sun synchronous orbit at 1000 km.</td>
<td><strong>SAGE III</strong></td>
<td>O₃, H₂O, OCIO, NO₃, NO₂, aerosols</td>
</tr>
</tbody>
</table>
ANNEX II: Space Remote Sensors producing NO$_2$ data

<table>
<thead>
<tr>
<th>Sensors</th>
<th>NO$_2$ product</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIAMACHY</td>
<td>Column</td>
<td>Tropospheric/Stratospheric</td>
</tr>
<tr>
<td></td>
<td>Vertical profile</td>
<td>10-100 km</td>
</tr>
<tr>
<td>MIPAS</td>
<td>Vertical profile</td>
<td>15-50 km</td>
</tr>
<tr>
<td>GOMOS</td>
<td>Vertical profile</td>
<td>20-100 km</td>
</tr>
<tr>
<td>GOME</td>
<td>Column</td>
<td>Trop./Strat</td>
</tr>
<tr>
<td>FTS</td>
<td>Vertical profile</td>
<td>10-100 km</td>
</tr>
<tr>
<td>MAESTRO</td>
<td>Vertical profile</td>
<td>10-100 km</td>
</tr>
<tr>
<td>TES</td>
<td>Vertical profile</td>
<td>10-34 km</td>
</tr>
<tr>
<td>OMI</td>
<td>Column</td>
<td>Trop./Strat</td>
</tr>
<tr>
<td>HIRLS</td>
<td>Vertical profile</td>
<td>20-60 km</td>
</tr>
<tr>
<td>GOME 2</td>
<td>Column</td>
<td>Trop./Strat</td>
</tr>
<tr>
<td>OSIRIS</td>
<td>Vertical profile</td>
<td>10-48 km</td>
</tr>
<tr>
<td>HALOE</td>
<td>Vertical profile</td>
<td>15-130 km</td>
</tr>
<tr>
<td>SAGE III</td>
<td>Vertical profile</td>
<td>10-45 km</td>
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</table>